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63-1-5

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Report 8926-065

Material - Fuels and Lubricants - RP-1 Fuel

Physical Properties

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11 December 1958

Published and Distributed
Under
Contract AF33(657)-8926

Post Office Box 1950 San Diego 12 California CYpress 6-6611
Material Post Office Box 2071 BRoadway 3-8000 Accounting Post Office Box 510

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Material - Fuels and Lubricants - RP-1 Fuel

Physical Properties

Abstract

The density and viscosity of RP-1 fuel were determined by use of a modified Sprengel type pycnometer and a standard Ostwald viscometer, respectively. The thermal conductivity of liquid and solid RP-1 and the linear coefficient of thermal expansion of the solid RP-1 were determined with special apparatus. The specific heat and cubical coefficient of thermal expansion of liquid and solid RP-1, respectively, were calculated from appropriate physical data. The data obtained were as follows: (a) density of liquid, 0.7967 ± 0.0005 cm/ml at 25°C, 0.7987 - 0.0036 (t°C - 25.0) cm/ml, -45 to + 25°C; viscosity, 1.96 cp or 2.45 x 10^{-2} stoke at 20°C; thermal conductivity of liquid (332 ± 5) x 10^{-6} cal gm/cm^2 sec deg at 28°C; thermal conductivity of solid (6.4 ± 1.0) x 10^{-4} cal cm/cm^2 sec deg at 78°C ?.0 x 10^{-4} cal cm/cm^2 sec deg at -196°C (estimated); specific heat liquid, +0.53 cal/gm deg at 28°C; cubical coefficient of expansion of liquid, (8.7 ± 0.1) x 10^{-4} cc/cc deg from -40 to 25°C (calculated); linear coefficient of expansion, (61 ± 4) x 10^{-6} cm/cm deg -190 to +50°C.

Reference: Malik, J. G., Graber, F. W , Keller, E. E., "Determination of Various Physical Properties of RP-1," General Dynamics/Convair Report MP 57-684, San Diego, California, 11 December 1958. (Reference attached).

STRUCTURES-MATERIALS LABORATORIES

CONVAIR

A DIVISION OF GENERAL DYNAMICS CORPORATION

SAN DIEGO

REPORT 57-684

DATE 12-11-58

MODEL 7

TITLE

Report of the Determination of

Various Physical Properties of

RP-1

Model: 7

Contract No.: AF04([illegible]7)-104

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NO. OF PAGES 7

NO. OF DIAGRAMS 0

REVISIONS

NO.	DATE	BY	CHANGE	PAGES AFFECTED
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ABSTRACT:

The density and viscosity of liquid RP-1 (a kerosene-like hydrocarbon mixture) have been experimentally determined using a modified Sprengel type pycnometer and a standard Ostwald viscometer, respectively. The thermal conductivity of liquid and solid RP-1 and the linear coefficient of thermal expansion of solid RP-1 have been experimentally determined using modified apparatus. The specific heat and the cubical coefficient of thermal expansion of liquid and solid RP-1 respectively have been calculated from the appropriate physical data.

OBJECT:

The object of this test was to determine the following physical properties of RP-1:

A. Density of the liquid

B. Viscosity of the liquid

C. Thermal conductivity of the l id

D. Thermal conductivity of the so

E. Specific heat of the liquid

F. Cubical coefficient of thermal expansion of the liquid

G. Linear coefficient of thermal expansion of the solid

RESULTS:

A. Density, d

$d = 0.7987 \pm 0.0005$ gm/ml at 25.0° C.

Temperature range -45 to +25° C.

$d = 0.7987 - 0.0036\ (t° C - 25.0)$ gm/ml.

B. Viscosity, ν

$\nu = 1.96$ cp or 2.45×10^{-2} stoke at 20° C.

C. Thermal Conductivity of Liquid RP-1, h

$h = (332 \pm 5) \times 10^{-6} \frac{cal\ cm}{cm^2\ sec\ deg}$ at 28° C.

RESULTS: (Continued)

D. Thermal Conductivity of Solid RP-1, h

$$h = (6.4 \pm 1.0) \times 10^{-4} \frac{\text{cal cm}}{\text{cm}^2 \text{ sec deg}} \quad \text{at } -78^\circ \text{ C.}$$

$$h = 10. \times 10^{-4} \frac{\text{cal cm}}{\text{cm}^2 \text{ sec deg}} \quad \text{at } -196^\circ \text{ C.}$$

(estimated)

E. Specific Heat of Liquid RP-1, Cp

Cp = + 0.53 cal/gm deg at 28° C.

(calculated) 6.7% average error

F. Cubical Coefficient of Thermal Expansion of Liquid RP-1, β

$$\beta = (8.7 \pm 0.1) \times 10^{-4} \frac{\text{cc}}{\text{cc deg}} \quad \text{from } -40 \text{ to } 25^\circ \text{ C.}$$

(calculated)

G. Linear Coefficient of Thermal Expansion of Solid RP-1, α

$$\alpha = (61 \pm 4) \times 10^{-6} \frac{\text{cm}}{\text{cm deg}} \quad \text{from } -190 \text{ to } -50^\circ \text{ C.}$$

$$\alpha = (104 \pm 8) \times 10^{-6} \frac{\text{cm}}{\text{cm deg}} \quad \text{from } -190 \text{ to } -50^\circ \text{ C.}$$

(impurities present)

TEST PROCEDURE:

The following is a brief summary of the methods and apparatus used in the determination of these physical properties with the results of the work.

A. Density

The density of liquid RP-1 as a function of temperature was determined over the temperature range -45 to 25° C. A specially constructed modified Sprengel type pycnometer was used which kept the limit of error within ± 0.0002 gm/ml. The pycnometer consisted of a glass U-tube holding approximately 2.5 ml. To the two open ends were attached capillary tubes marked to 0.05 ml total volume, calibrated to 0.001 ml, and estimable to ± 0.0002 ml. At the ends were glass-stoppered covers to prevent evaporation. The volume of the U-tube part of the

TEST PROCEDURE: (Continued)

A. Density (Continued)

pycnometer was determined using water and mercury as standard$. Then, the unknown was placed in the pycnometer, weighed, and placed in a constant temperature bath. The additional volume was read on the capillaries and added to the calibrated volume. The density at this temperature may then be calculated. The temperature bath was lowered, and the new decreased volume measured. The weight was identical, so the new density may be calculated. This was repeated over the selected temperature range. The equation relating density vs. temperature was then readily obtained from the data.

B. Viscosity

A standard Ostwald viscometer was used to determine the viscosity. The particular value given in the results at 20° C. was that used to calculate the specific heat. (Reference, Deniels et. al., "Experimental Physical Chemistry" (195(

C. Thermal Conductivity of Liquid RP-1

The apparatus consisted of a glass tube 32 cm long, sealed on the lower end, and of such diameter that a 1 cm length contained a volume of 1 cc. The liquid RP-1 was introduced to the 24 cm mark. A 10 cm long heater supplied by a constant voltage line was wrapped around the upper end of the tube 2 cm below the top of the liquid. Another tube of larger diameter was fitted concentrically at the bottom and contained the same liquid as that being measured. It acted as a thermal equilibrator, evening out the external uncontrolled thermal shocks. A movable chromel-alumel thermocouple was introduced 4 mm below the heater. The height of the thermocouple tip was determined with a cathetometer. Upon heating, isothermal equilibrium conditions were established with a constant heat radiation loss through the liquid sample. The height and temperature of the thermocouple were recorded at various points in the liquid over the existing temperature gradient. This procedure was followed for the reference liquid and the unknown.

By the use of Jakob's formula for the heat conduction in short rods, the thermal conductivity of the unknown was calculated. The formula is:

$$\frac{k_a}{k_b} = \left[\frac{\log\left(n_b + \sqrt{n_b^2 - 1}\right)}{\log\left(n_a + \sqrt{n_a^2 - 1}\right)}\right]^2$$

$$\text{where } n = \frac{t_0 + t_2}{2t_1}$$

TEST PROCEDURE: (Continued)

C. Thermal Conductivity of Liquid RP-1 (Continued)

The subscripts a and b refer to the reference and unknown substances while t_0 is the temperature at the source and t_1 and t_2 are the temperatures at the distances L and 2L respectively. The thermal conductivity constants are represented by k. (Reference, "Heat Transfer", Vol. 1, Max Jakob, Convair Library No. QC 320.J22)

An approximate relationship which is easier to calculate k is given by

$$k_a/l_a^2 = k_b/l_b^2$$ where k_a and k_b

refer to the thermal conductivity of the reference and unknown liquid while l_a and l_b are the lengths in cm for identical equal differences in temperature. (Reference, Rev. Sci. Instr., 21 905 (1950).)

Because this was a comparative relationship and not an absolute determination, three liquids of known thermal conductivities consistent with one another were chosen as standards.

D. Thermal Conductivity of Solid RP-1

Thermal conductivity apparatus for organic solids such as RP-1 are not readily available as standard equipment. Special considerations and conditions require specialized apparatus. Therefore, the simplest set-up possible to determine this property was employed. It consisted of a tube similar to that employed in the determination of the thermal conductivity of the liquid sample. The heater was an internal exposed wire of predetermined resistance. The tube was submerged in a dry ice-isopropyl alcohol bath to obtain the desired low temperature. Insulation was needed outside the exposed part of the tube to reduce heat losses through the glass. A single, movable thermocouple would not be visible so four thermocouples were employed. These were sealed through small holes in the glass, the tips being centered and 1.0 cm apart from each other. The tube possessed a 1 sq. cm. cross-section. The RP-1 was introduced to cover the bottom two thermocouples. The standard or reference liquid was placed over the solid RP-1 covering the top two thermocouples and extending up to the heater. A substance was chosen that would be just above its freezing point for excellent thermal contact with the solid RP-1. Upon heating, isothermal equilibrium conditions were established with constant heat losses. The reference liquid was chosen with a thermal conductivity close to that of RP-1 to minimize differences.

TEST PROCEDURE: (Continued)

D. Thermal Conductivity of Solid RP-1 (Continued)

The equation for the conduction of heat through a substance is given by

$$\Phi = -KA \frac{dt}{dx} \cong -KA \frac{\Delta t}{\Delta x}$$

where Φ is the rate of heat flow (cal/sec.)., K is the thermal conductivity (cal. cm/cm^2 sec. deg.), A is the area (cm^2) and dt/dx is the temperature gradient (deg/cm). Since A and Δ x are predetermined constants for the apparatus, if Δt is determined experimentally for a liquid of known K, then the heat flow can be calculated. It is assumed that this is the heat flow entering the unknown under the conditions of isothermal equilibrium. Therefore with A and Δ x being predetermined constants for the apparatus, if Δ t is determined experimentally, for the unknown, its thermal conductivity can be calculated. The final equation becomes s ly

$$K_u = \frac{\Delta T_k}{\Delta T_u} K_k$$

where the subscripts refer to unknown and known substances. This holds true for the cell of constant cross-section and equal distances between the thermocouples.

Other constant temperature baths are used for other temperatures and other reference liquids may be used. (Reference, Partington, "An Advanced Treatise on Physical Chemistry" Vol. 2, 1954).

Knowing the thermal conductivity of solid RP-1 at one temperature, it is possible to estimate the value at a lower temperature by comparing the K vs temperature plots for similar substances in this range. An estimate was similarily made for the solid RP-1 at dry ice temperatures from the liquid values and compared favorably with the experimentally determined value.

E. Specific Heat

The value for the specific heat of liquid RP-1 was calculated from S. F. D. Smith's equation relating the specific heat, thermal conductivity, density, molecular weight, and kinematic viscosity of a substance. The equation is particularily valid since the constants are based on experimental data from a large number of related

TEST PROCEDURE: (Continued)

E. Specific Heat (Continued)

hydrocarbons. The average error in the calculation of h was found to be 6.7%. The equation is

$$k = 0.000011 + \frac{(Cp - 0.45)^3}{155} + \frac{\sqrt[3]{d/M}}{800} + \frac{\nu^{1/9}}{6000}$$

where k, Cp, d, M, ν are the thermal conductivity, specific heat, density, average molecular weight and kinematic viscosity respectively. (Reference, Max Jakob, "Heat Transfer" Vol. 1).

F. Cubical Coefficient of Thermal Expansion of Liquid RP-1

Except for a special apparatus which compensates for the expansion and contraction of the container which holds the liquid to be measured the usual apparatus is beset with this cort. [illegible] difficulty and an involved correction is necessary. (Referen[illegible] Z. Phys. Chem., 71 385 (1910).) Therefore it was noted that a calc[illegible]ted value of the cubical coefficient of thermal expansion fro[illegible] he rather accurate density measurements would quickly result in a reputable value and eliminate the extensive experimental procedures involved.

The relationship is

$$d_2 = \frac{d_1}{1 + \beta \Delta t} \quad \text{where } d_1 \text{ and } d_2$$

are the densities at the temperatures t_1 and t_2 and Δt is the temperature difference $t_2 - t_1$. The cubical coefficient of thermal expansion beta has units of c.c./c.c.-deg.cent. or simply deg^{-1}.

The accuracy of the formula was checked using water as the standard. The density data was taken from the Rubber Handbook, 38th Ed. The results were ± 4% for the value of beta. (Reference, Partington, "An Advanced Treatise on Physical Chemistry", Vol. 3).

G. Linear Coefficient of Thermal Expansion of Solid RP-1

The determination of the linear coefficient of thermal expansion of solid RP-1 from -190° C. to -50° C. consisted of determining the amount of contraction of a given length of solid RP-1 in a capillary tube and of solid pieces of various dimensions by use of a microscope with a graduated eyepiece.

TEST PROCEDURE: (Continued)

G. Linear Coefficient of Thermal Expansion of Solid RP-1 (Continued)

The capillary tube method proved unsuccessful because of cracking, breaking, and sticking to the tube. A linear contraction measurement was impossible.

The continual condensation of water vapor and carbon dioxide as frost at the lower temperatures obscured the vision rather quickly. After several more elaborate setups, it was finally determined that by placing 2 to 20 drops of liquid RP-1 on powdered dry ice contained in a culture dish and covering with the top half, the frosting was reduced to a minimum. After several minutes for thermal equilibrium to establish the cover was removed and several readings were taken of the edges of the pellet with the graduated eyepiece. Then liquid nitrogen was carefully poured over the pellet until thermal equilibrium was again obtained at the lower temperature. Several more readings were recorded with further applications of liquid nitrogen between. This tended to maintain the thermal equilibrium and minimize the frost. The RP-1 pellet was in a depression in the dry ice and lower than the sides of the dish. This effectively placed it in an atmosphere of cold pure nitrogen. The contraction was calculated from the readings involved. Dividing this by the original length and the temperature difference gave the length of expansion per unit length per degree.

It should be mentioned that extensive work was performed with these solid RP-1 pellets to determine the exact equilibrium temperatures when the pellet was resting on dry ice and when doused with liquid nitrogen. Also the time to accomplish and maintain these equilibrium temperatures were carefully determined. This was done with a chromel - alumel thermocouple which was initially calibrated over the temperature range and imbedded at various places in the pellets to determine the temperatures. There was an excellent uniformity and consistency with the procedure.

It must be noted that after the RP-1 has been heated for sometime during previous thermal conductivity tests, the value for the linear expansion increases by as much as 70%. During these heat tests, no precautions were taken to prevent loss of the lighter fractions. Also, the red-brown, flexible covering of the thermocouple wire placed in the RP-1 became colorless and rather hard and brittle. The color of the RP-1 itself changed perceptibly. This evidence indicated that some substance may have been extracted and is responsible for the large change. Further tests to determine the effect of various impurities on this property were not carried out.

NOTE: The data from which this report was prepared are recorded in Laboratory Note Book No. 3002.